Landscape-use optimisation with regards to the groundwater resources protection in mountain hardrock areas, LOWRGREP

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Part 1: Publishable Final Report	Non Confidential

1.1 Executive publishable summary:

LOWRGREP is the acronym for Landscape-use Optimisation With Regards of Groundwater Resources Protection in the Mountain Hardrock areas.

The objective of the project is to assess the degree of interference of anthropogenic activities with the hydrosphere in mountain regions. Each of the test regions represented a certain model area characteristic of different degree of protection. Investigations have been made at two scales: very local (some km^2 or less) and regional scale (about some hundred km^2) in four countries: Czech Republic, Germany, Spain and France. Monitoring system showed a decrease of sulphur deposit in Germany as well as in Czech Republic. On the other hand, investigations showed an increase of nitrogen deposit in the same countries.

A method has been proposed to evaluate the acidification and it appears that this method fits well with the obtained data if the studied area is great enough (some tens km^2). The weight of input parameters are to be checked for every region.

Nitrogen charge on to the soils and then in water is also related to agricultural practice. It appears that landscape optimisation (from the view point of groundwater resources) suggests a limit of about 1 cattle per 0.5 ha.

A relationship between land-use change and run-off change is difficult to put in evidence, because a great number of parameters vary and this change is often very slow.

Scarcity of water in some studied regions also brings to the idea that groundwater has to be preserved and that some cultures which need a lot of water are to be avoided. And more generally a sustainable administration of the water resources bound to the aquifers of the hard rocks should outline: the use of these aquifers, preferably, and in some cases exclusively, must be for populations' supply.

Modelling tools also have been used as well as GIS. Modelling was used to estimate groundwater recharge, and run off. Different models were used (SACRAMENTO, CHAM, BROOK) and one model was built up.

GIS was used to make maps of pollution load and vulnerability maps to risk of acidification.

A simulation tool also has been built. In order to take to account the changes in land-use (for instance, with varying runoff coefficient) (so, anthropogenic influence). Simulations can be made for long term period (thirty years) and results have now to be checked with existing set of data.

A Knowledge Base built in the web-site of the project allows a user’s friendly form, and all kind of data (slides, texts, maps) can be stored in this site. Different levels of confidentiality

allow to use this web-site for exchanges between experts as well as a site in order to get public information.

1.2 Publishable synthesis report:

Objectives and strategic aspects: the project is focused on evaluation of all factors which may influence the hydrosphere in mountain areas of the European Union countries, with particular view on groundwater. Some partial points are to be answered, for instance: to assess the influence of atmospheric deposition on quality of groundwater, to assess the influence of landscape-use onto groundwater, to assess the vulnerability of various hard rocks to pollution.

The second aim of the project is to verify the reliability of scientific knowledge. The achieved knowledge and data will be used to set up model alternatives of landscape development in mountain areas. This will give some suggestion for optimum landscape development. A software Hydrodesusma must be built, which will be a Decision Support System for land use with regards to groundwater resources protection. This includes some suggestions concerning EU policies of water and land-use.

Scientific and technical description of the results: LOWRGREP Project was divided into 6 workpackages. The first one, "identification of the areas", had to describe the studied regions (pollution problems, land-use policies, etc), to build a common frame for the work (methodology of sampling, data set, etc…) and to select small experimental catchments.

The second Work package was: "assessment of local landscape use impact on hydrosphere in the Mountain Regions". This task was mainly devoted to monitoring of run-off as well as hydrochemical changes. Concerning the impact of landscape use changes onto run-off, it is very difficult to make a very clear link; this is due to the fact that a great number of parameters are involved and their common impact is difficult to show. Changes are very often gradual and, so, difficult to put in evidence. Concerning the quality of water it has been shown that the trend is decreasing for sulphur deposit, but increasing for Nitrogen. This point has also to be related with the nitrates and good agricultural practices.

The third workpackage was the "assessment of regional human activity influence onto the groundwater quality and Partners established "Pollution load maps" and risk analyses of all factors onto groundwater. Results are that an optimum value for cattle in these regions is of about 1 cattle per 0.5 ha. Other result is that, for a sustainable management of water, these groundwater bodies have in some cases to be reserved for population's supply.

Following task was "perspective of the regional groundwater exploitation in the mountain regions from the quantitative standpoint"; the objectives were to determine quantitative limits for groundwater exploitation in the studied mountain regions on the regional scale. The results are not precise in reason of the lack of data (mainly transmissivity) in the studied area.

The workpackage 5 was Hydrogeological Decision Support System in the Mountain Areas: this decision support system is built with a Geographical Information System, and some application, the first one being a vulnerability evaluation module, and the second one a modelling and simulation tool. This modelling and simulation tool can evaluate the runoff changes of a river with the changes of land-use on a long term period (for instance 30 years). It has been checked for only a small period of time (due to the lack of data for a long term) and for small catchment areas. The use of this simulation tool on the regional scale will need improvement of the model.

The last task was the testing and dissemination of Hydrodesusma. Testing has been made on a small catchment and some other tests on other catchments are to be made in order to know precisely the precise possibilities of this tool. Dissemination is made with publications of the works in scientific papers and in conferences.

Part 2: Detailed Final Report

2.1 Objectives and strategic aspects:

The project is focused on the evaluation of all the factors which may influence the hydrosphere in hard-rock mountain areas of the European Union countries, with particular view on groundwaters.

The major objective of the project is to give a hierarchy between the different factors which influence the quality of water in mountain areas. This includes a wide and complex spectrum of factors of natural or anthropogenic origins. In order to achieve the final goal, some partial questions are to be answered, among them: to assess the influence of atmospheric deposition on the quality of groundwaters in mountain regions; to assess quantitative limits in permeability and transmissivity of hard rocks…

The second important target is to verify the reliability of the scientific knowledge. In order to fulfill this objective, the achieved knowledge and data will be used to set up various model alternatives of landscape development.

The abovementioned activities shall result in suggestions for optimum land-use development from the view point of groundwater protection. Partial output of this work will be the assessment of efficiency of implementation of European Community directives and national rules for groundwater protection.

The project output in the field of data processing will include the software: Hydrogeological Decision Support System in the mountain area: Hydrodesusma.

2.2 Scientific and technical description of the results:

WP 1 Identification of the Areas:

This Workpackage nº1 deals mainly with the first identification of areas (catchment experimental areas) to be studied during the project. Several tasks related below were presented by the deliverables: D1 (Review of environmental and socio-economic conditions) and D2 (Methodology unification).

1.1. Selection of small experimental catchments and demarcation of areas for regional studies:

In every partner country a selection of areas to be tested was made. A multi-criteria approach was applied in order to find different conditions (climatic, industrial activities, environmental problems…).The selected areas were: In Czech Republic, two areas: Krusné Hory Region and Sumava region. Catchments of Vysoka Pec, Jezery and Nacentin in Krusne and Spulka and Albrechtec in Sumava. The interest was to have a difference in anthropogenic conditions between the two regions. In Germany the Region of Rotz-Schontal (Upper Palatinate), study area of the Lehstenbach catchment, and Bodenmais. In Spain two more areas: Guadarrama region (Lozoya Valley) and Iberian Range district, and, in France, the Mont Lozère region was studied.

All these regions have a well documentation background on data (meteorological, chemical, soils, geological data, gauging stations files, etc), in order to compare historical with current data.

The extents of regions are different from more than thousand square kilometres (catchments of Czech Republic) to hundreds of hectares: Lehstenbach (Germany). The figure 1 shows the locations of the investigated areas.

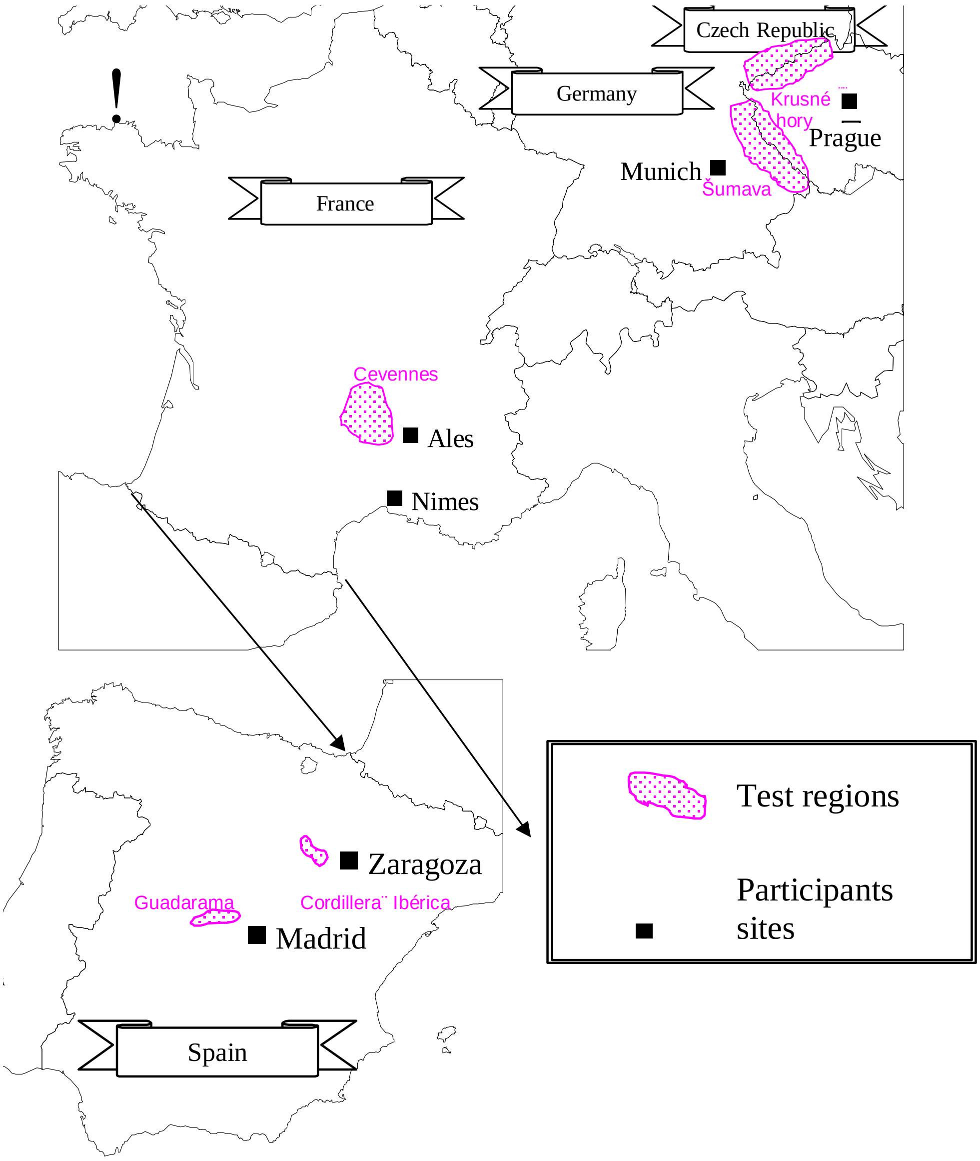

Figure1. Location of test regions

1.2. Review of current pollution problems in partner countries; identification of conflicting policies between the groundwater protection and other sectors:

Generally speaking, we find two different conditions between northern and southern countries. In Germany and Czech Republic, acid rain (atmospheric deposition) seems to be the main problem. As a consequence the apical parts of the mountain range suffered from mass extinction of the forest cover, which led to stronger erosion degradation of surface and groundwater quality including negative impacts on hydrological regime in general. According with the current data obtained in small catchments of the project, the lower concentrations of sulphur in acid atmospheric deposition show prolonged trends. Meanwhile the increase in nitrogen (ammonia and/or nitrates) due to traffic and fertilisers applied in agriculture practice, is now under concern. This conclusion is for both northern and southern countries of Europe. Recreation and rural tourism very frequent in mountain areas is another environmental problem to be envisaged in future. On the other hand, uncontrolled anthropogenic activities in the region so called "black triangle" (junction of borders of Czech Republic, Germany and Poland) had been studied. The region is characterised by strong accumulation of heavy industry, chemical plants, power stations and open-cast mines for lignite. Different degrees of conservation of the Landscape (National or Regional Parks) have also been in consideration.

The LOWRGREP project has identified some sources of pollution in both surface and groundwaters. Among them the more significant are the acid deposition (soils and waters), agriculture practices, timber uses, salting of road (in Germany), military camps (Germany and Czech Republic), and cattle raising (mainly in Spanish's catchment).

1.3. Set up of all collected data and their transfer into computer form, elaboration and set up of a uniform method for sampling and data processing

During the workshops organised in Czech Republic (Rohanov) and Madrid was discussed general approach in order to share data between teams. According with the agreements we load the web-site, under a protected access, all data in order to inform all teams. The Krasny approach on regional transmissivity to compare data was also approved. The Sacramento programme for water balance in small areas was discussed. Furthermore, the CUTTOS approach on decomposition of hydrogram was accorded to be accomplished. Otherwise, a general agreement related with water samples campaign in order to make homogeneous all data was accorded. For instance, the bulk rainfall and throughfall precipitation had been made identically in all areas, by mean of identical instrumentation fields tools.

1.4. Assessment of local and regional land use policy in partner countries:

In every studied catchment of the project, lithological features, vegetation cover, land-use practices, density of settlement, agricultural practices, industrial activities, cattle raising activities, disposal wastes areas, leisure activities… had to be taken in consideration. Legislative measures (very wider in different areas) have also been studied. The conclusion is that the legislative measures on protected areas are a very successful tool for maintaining natural conditions of waters (surface and groundwater).

In Krusne Hory, the forest is a dominating element due to mountain character of the study area. Farmland is almost negligible. In all studied areas, the forestry is dominant. Arable areas are almost negligible in all catchments. In Guadarrama (Madrid) and Ibérica Range (Zaragoza) there is a few industrial development. Only cattle raising is worth to be quoted. In Czech Republic the power plants are dismissing, which means current better atmospheric conditions.

1.5. Complete survey of natural and socio-economic conditions in all the studied and compared regions:

At the beginning of LOWRGREP project a complete study of natural and socio-economic conditions of the areas selected was accomplished. Common features of the areas are the fact that they are on hard rock areas and with elevation between 500m and 1500m. But the areas are very different from climatic and anthropogenic point of view.

The rainfall is variable from areas with precipitation being more than 1800 mm/year (Parc National des Cévennes in France) to less than 600 mm in Ibérica Range. In the catchments of Germany, the precipitation is close to 850 mm/year and the evapotranspiration between 450 and 520 mm/year. In Spain it is much higher, raising 650 mm/year in Ibérica Range.

It is worth to keep in mind that the areas in Germany and Czech Republic suffer from an important decrease of population due to the second World Wear. In France, this decrease began with the First World War. This means that extent areas are in conditions very close to “natural”.

From the geological point of view, all areas are characterised by hard rocks outcrops.

WP 2 Assessment of the local landscape use impact on hydrosphere in the mountain regions:

2.1. Assessment of hydrochemical balance in the network of the experimental small catchments:

pH was measured in rain as well as in groundwater. Great variations can be observed between sites. From around 4.5 in “Na Lizu” catchment, mean pH value is 5.1 in Germany (Lehstenbach); 5.07 in France (Mont Lozère) and 7.06 in Spain (Vicort).

In order to make assessment of the chemical balance, a monitoring of atmospheric deposition and chemical analyses of water has been realized. Concentrations in major ions were measured according to a common standard. The balance of these elements could be calculated (Ca^{2+}, Mg^{2+}; Na^{+}; SO_4^{2-} ; Cl^{-}). Calculation indicates that balances for Ca^{2+}, Na^{+}, Mg^{2+} and K^{+} are negative in the catchments of France and Spain, as well as in Germany. In order to get a trend, some data stored in archives were also used. It appears that the sulfur deposits are decreasing in Czech Republic from 1990 as well as in Germany. Long-term measurements indicate that nitrogen shows an increase in Czech Republic, this trend being not so clear in Germany. Other detailed analyses have been made which indicate that this chemical balance is influenced by very various factors: the atmosphere (wind direction making a difference between a wind with an important pollution load and another wind), the species of trees (main difference being between coniferous and deciduous trees), the nature of the soil (some soil having buffering capacity), the nature of the hard rock (which can influence the chemistry of water), the time given to the flow and the history of the catchment (influence of clear cutting made in the years 1987-89). Different measurements also indicated that chloride can be a very clear anthropogenic indicator (very close to the roads, with a very precise time of apparition). All these influences make impossible to give a unique answer to so different catchments with different climates, different vegetations, different soils and different rocks. All these facts indicate that a modelling-tool must have a lot of input data in order to give some realistic estimation.

2.2. detailed analysis of run off changes in hard-rock regions:

Every catchment has been equipped or was already equipped with gauging station in order to have measurements of brook flows. A software, CUTTOS 2, has been developed by Zaragoza University; this software allows to distinguish different phases during the decrease of flow after a rainy event. This software has been applied in Spain and in Germany. The result allows to make a difference between the surface runoff and the groundwater. Other simulation tools have been used for estimating the impact of land use to runoff of brooks or rivers: the models SACRAMENTO, BROOK and the simulation tool Hydrosimul, which will be presented in a next paragraph. The main problem is to find real data from a site which has been the place of an important change in land cover. One of the studied catchment was La Latte, where a clearcutting of forest took place in years 1987-89 and when run-off was measured. Other comparisons between simulations and measurements were made on Czech rivers. The results indicate that the interpretations need to be carefully done because a great number of parameters play a role and this work needs to check a great number of hypotheses. Simulation tool also permits to evaluate the impact of possible climatic change on run off of the rivers. So, if calibration and validation of the model are made, it becomes possible to have an estimation of possible change. The first problem which appears is the variability of this run-off. As the flows of rivers are strongly related to weather, it is necessary to have a great set of

data in order to have a good estimation of the mean values, the standard deviation, and eventually of a trend. This was also a reason to choose catchment where data already exist.
Another difficulty is that changes very often are very slow changes (for instance the growing proportion of the forest in the total area of Cévennes is of 1% of total area every year). This slow trend can only be measured on long time-lag and it is the same for its influence. Some opportunities can exist, like clear cutting. In this case, the limiting factor for precision is the rain variability. So, when we study the influence of land-use changes, we are in front of a long term question.
Another fact has to be mentioned: in land-use changes, we have a lot of parameters which surely interfere in the run-off and very probably with another weight after the change. For instance, the change of a forest into grass-land is not immediate (it is more obvious in the opposite sense); and the parameters which also change are: interception of precipitation, evapotranspiration; perhaps the creation of roads for the trucks involved in the deforestation will be necessary, and it will induce a superficial run-off ; the growing of grass during and after deforestation will also have an influence, probably also the apparent density of soil which could be compacted by the trucks, etc…
In other words, the prediction for run-off changes needs a very precise knowledge of the catchments and very precise measurements in very different fields of knowledge because needed data are: data from the meteorology, data concerning the vegetation, data of the soils and the rocks, data of the run-off with very small time base for measurements, but for long period of time for the recording (as long as possible). These data are gathered from different institutions, which brings a technical problem for setting together these data. These sets of data then allow different calculations. For instance, it is possible and useful to combine different time scales for the evaluation of differences between simulated and observed flows. Daily time series seem desirable, and variation in rain between two successive years can lead to use accumulated differences and moving averages (every of this technique needing a lot of data). The quality of a prediction concerning the variation of run-off due to land-use will be strongly dependent of the quantity of measurements we have. Then the quality of the calculations will probably need different mathematical treatments, particularly to avoid statistical bias due for example to weather variability.
It means that the decision support built in this project, Hydrodesusma, is only a prototype which needs to be tested and improved.

WP 3 Assessment of the regional human activity influence on the groundwater quality in the mountain regions:

As mentioned in this title, the studied regions are mountain areas. It means that the local activities are more farming and tourism than industry. An exception to this rule is the region of Krkonose, in Czech Republic, where the proximity of the industry is an important factor of human activity influence. Another important fact: because mountain regions receive more precipitations than other regions, they will be more subject to atmospheric pollution related with rain. So the main factors to study concerning the human influence are: first, an ***indirect influence*** of industry or of other pollutions sources ***through air pollution*** and, secondly, ***direct and local pollutions*** by other human activities, mainly agriculture.

3.1. Regional risk of acidification:

Mineralogical composition of soil cover as well as that of the bedrock appears to be the most important factor influencing the acidification of groundwater in mountain regions. If the soil contains carbonate minerals, mostly calcite and dolomite, then these soils can neutralize acid rains and maintain the pH of groundwater close to 7. In such a case, the infiltration of acid atmospheric precipitation is being manifested only by enhanced hardness and acidity of groundwater. If there is a lack of carbonates in soil, then the free hydrogen ions react with alumino-silicates. These kinetically controlled reactions lead to release of aluminium ions, which, apart from reducing partly the amount of free hydrogen ions, maintain the groundwater to be acid. As a by-product of these reactions is the reduction or complete disappearance of hydrogen-carbonate ions. The most intense acidification of groundwater was observed at higher altitudes, where vegetation and soil cover are often completely missing. The type of vegetation is closely connected with the type of soil. Leaves of deciduous trees are the source of organic carbon in soil, consequently even a source of free carbon dioxide and hydrogen-carbonate ions following the oxidation of organic carbon. These components represent otherwise weak but still certain buffer system being able to reduce fluctuations in concentration of hydrogen ions. This phenomenon does not occur in the case of coniferous trees.

Dry deposition also plays an important role in acidification of groundwater. Dust particles caught by vegetation or soil and absorbed sulphur and nitrogen oxides are washed down by atmospheric precipitation and together with it reach the groundwater. Windward slopes exposed to prevailing winds are therefore more endangered than leeward slopes.

Rapid changes in water quality, showing piezometric groundwater level, are characteristic of mountain regions. Certain proportion of sulphate and aluminium ions, which remain to be absorbed in unsaturated zone, become released at groundwater-level rise.

Hrkal developed a methodology to build a map of vulnerability of the risk of acidification due to atmospheric pollution. This method uses a Geographic Information System (GIS) with different layers involved in this process of water acidification. Layers are: the geological nature of the rock, the nature of the soil cover, the morphological map, the topography (in order to share between exposed hills to wind and leeward slopes) and the vegetation cover (forest being more exposed than grassland). This methodology has been applied on different test sites. Data from monitoring at the regional scale have been used when possible to compare the results with the results of this method. It appears that the evaluation of the relative importance of different factors is to be changed to apply the method in Cévennes (South of Massif Central). This is due to the fact that the winds with the main pollution do not have the same origin than the polluted air in Czech Republic. The same observation could be done in Spain (Zaragoza region). Regional groundwater monitoring has been used in order to precise the conclusions from the vulnerability maps. A strong correlation can be established in Czech Republic (Krusne Hory Mountains) between the relatively high pH-value and the presence of HCO_3 in water.

3.2. Direct and local pollutions:

a) The effect of farming and forestry on groundwater quality:

Mountain regions are traditionally used for animal husbandry. As can be demonstrated on the Spanish localities, the impact of pasturage on groundwater quality is not serious providing the animals are dispersed over a large area. In contrast, concentration of cattle during winter months led to considerable increase in the content of nitrates in waters in the neighbourhood of farms. This fact becomes even more relevant and warning in the case of large-scale breeding in the Czech Republic. However, even greater danger for groundwater pollution represent large-scale piggeries and poultry farms, relative to cattle breeding. The same danger could arise in Spain (Zaragoza region for the same reason). Due to a very extensive farming in the Cévennes area, this risk is avoided in this region. In Germany, the conclusion is that, despite of small areas of agricultural land use, nitrate is a problem in vicinity of villages as well as farmland. We have also to note that improvements are made. In the studied region near Madrid, the cattle raising is a very important activity, but the level of nitrates in water can be considered as natural and it has to be indicated that the land use planning, established because of its proximity to the natural Park of Penalara and as head water of the Lozoya River makes essential a consistency in the land use.

Fertilization of farmland in foothills also contributes to the increase of nitrates in groundwaters, particularly after torrential rains or snow thawing. This problem can be resolved by reasonable application of fertilizers. Moreover, the ammonium ions not absorbed by vegetation release a large amount of hydrogen ions, which contribute to further acidification of groundwaters. Excessive use of pesticides has also very negative and prolonged impact on groundwater quality. These pesticides were not in our common study of water chemistry and we mention these compounds to cover all the risks of pollutions.

The danger arising from forestry is in breaking of soil cover. The use of heavy agricultural machinery causes change in drainage, and another risk is in leak of petroleum and fuels and their infiltration in soil. Unfavourable composition of forest may also play a negative role in groundwater quality.

b) Traffic:

As previously written, motor traffic in particular poses a danger on groundwaters due to generation of nitrogen oxides. In contrast to air pollution caused by sulphur dioxide, the nitrogen oxides pollution is difficult to reduce. Another danger arises from accidents during which leak of chemical substances into groundwaters may occur. The limiting factor of this risk is the low number of these potentially pollutant trucks. Using de-icing salt for roads during winter months appears to be less important but still may represent occasionally very considerable increase in chlorides content in water. This example of pollution by chloride has been seen in Spain, in Czech Republic and in Germany, but still is a minor problem.

c) Settlements:

The population density in the studied regions is generally low and dispersed over relatively large areas. Nevertheless, enhanced concentrations of nitrates in waters were observed in the neighbourhood of residential and industrial areas. The sewage drained straight (without sewage purification or waste water treatment) into streams may also cause some serious problems. In the Cévennes region, we have to note that the density of inhabitants is very low (12 hab/km^2), a great part of them being in the village “Le Pont de Montvert” where there is a waste water treatment plant, so that settlement does not appear like a cause of pollution. In Germany, the settlements do not appear as a risk, except for accident. In the high Valley of Lozoya (Spain), the high quality of water indicates also that this region is not affected by pollutions due to settlements.

d) Mining and mineral resources:

No mining activities on larger scale are currently carried out in any of the studied regions. However, mining for silver, copper, tin, tungsten, cobalt, lead, uranium ores and other minerals took place in the Krušné hory Mts till the first half of the 20th century. Base metals and silver ores were extracted in Bavarian part of the Šumava Mts. Underground mining of gold in the environs of Kašperské Hory in the Šumava Mts attracted much attention in the nineties of the last century. However, this project was rejected by local administration because of possible ecological damage. Mining may have negative effect on groundwater quality even after its termination, as we can see at very local scale in Germany with a former mine from the 19th century (Bodenmais region).

e) Tourism and recreation:

The expansion of tourism and recreational exploitation of mountain regions bring environmental damages caused by motoring and construction of recreation facilities and the necessity to liquidate waste waters and sewage produced by them. The use of cycle paths and ski slopes or downhill race courses in particular may completely damage local vegetation and soil cover. This problem appears to be very general in all the studied areas, only the importance of ski being a difference between the regions.

WP 4 Perspective of the regional groundwater exploitation in the mountain regions from the quantitative standpoint:

4.1. Assessment of groundwater exploitable resources ("safe yield") in mountainous hardrock areas

When characterising the hydrogeology of an area two quantitative aspects should be taken into account:

- Static properties of the aquifer system: geometry and anatomy of hydrogeologic bodies and spatial distribution of their hydraulic characteristics. No hydrogeologic environment is homogeneous and isotropic under natural conditions. Especially the hardrock environment is to be considered an intricate hierarchic system of hydrogeologic inhomogeneities of different scales.
- Geologic setting determines character of a hydrogeologic environment within which groundwater, the dynamic element, that is object of our attention, moves and is distributed. Groundwater recharge, which varies in time and space, determines sustainable natural groundwater resources. Under specific conditions, induced and/or artificial resources might complement natural resources.

Then, depending on hydrogeologic and climatic conditions, the limiting factor for groundwater resource development may be either:

- hydraulic properties of rocks or
- groundwater recharge.

Regional assessment and knowledge of these two aspects is indispensable for any decision on sustainable development and protection of ground water in more extended areas as regions, states, or even continents.

In arid and semi-arid regions, due to limited precipitation and high evaporation, natural groundwater recharge typically represents a limit to groundwater abstraction. Intensive groundwater withdrawals may result in long-term overdraft.

On the other hand, within the Earth's temperate climatic zone a relation between groundwater abstraction possibilities of different hydrogeologic environments, given by their hydraulic parameters, and available natural groundwater resources determine a safe yield of an area. In hardrock environments where high natural (renewable) groundwater resources reach in some catchments of summit parts of mountains up to 10-15 L/s km^2, recharge is sufficient to cover abstraction possibilities that are limited only by the transmissivity of rocks. Mountains with their surprisingly high natural groundwater resources, in spite of their relatively low transmissivity, often represent source areas, high enough to maintain flow of water courses in adjacent piedmont zones during dry periods. Therefore, when considering formation of natural groundwater resources (groundwater recharge) at the background of the earth climatic zonality (arid, humid, temperate etc.) vertical climatic zonality mostly due to hypsometric differences (mountains, lowlands etc.) is to be taken into account, too.

Under these conditions and, considering the present-day general trends towards water management optimisation and somewhere also existing water demand increase, adequately sited water wells or other water intake systems in hardrock areas can cover requirements on water supply for small communities, plants or farms and for domestic water consumption. In areas with high transmissivity of hard rocks groundwater abstraction possibilities might be high enough to supply even small towns. Therefore, within hardrock areas with sufficient water resources, scattered water intake objects can effectively cover water supply demands of at least part of consumers.

A hydrogeologic basis - adequate understanding of transmissivity and permeability distribution - is indispensable to reach this aim.

The studied regions in France, in Germany and in Madrid region did not have a lot of data concerning the transmissivity. Only Zaragoza region had some data concerning transmissivities. Surprisingly high transmissivity, especially compared with results from the Bohemian Massif, has been identified in the Paleozoic rocks of the Iberian range south of Zaragoza. In the other tested areas, no reliable data to assess the prevailing transmissivity were available. However, due to the fact, that both the Spanish test sites belong to distinct climatic zone, compared to Central Europe, natural groundwater resources might be limiting factor. As a consequence of a lack of data, the part “simulation of different scenarios” could not be developed.

As the available transmissivity data and the long term assessment of natural groundwater resources from the Czech Republic are evidently based on the most frequent data compared with other test sites studied within the LOWRGREP project, they might be used as a basis for the future comparison with available data in other partner states to draw preliminary conclusions regarding the possibilities of groundwater abstraction. The differences between the Iberian Range and also distinct climatic conditions have to be taken into account during any future studies aimed to exploitable groundwater resources.

4.2. Analysis of the factors that influence the groundwater resources:

Increasing amount of available data due to increasing demand for water and improved drilling technologies has stimulated efforts to **regionalise and generalise results from different**

fractured environments. Data on rock transmissivity, data on (natural) groundwater resources and on quality obtained by different methodological approaches offer **excellent possibilities of correlative hydrogeologic studies.** Thus new important results and conclusions can be drawn for better understanding of hydrogeologic properties of hard rocks both in local and regional scales and improvement of methodological approaches to be used there.

Transmissivity assessment and regional classification have provided a basis for a quantitative and objective expression, comparison and representation of prevailing transmissivity during the working out of the project LOWRGREP. Hydrogeologic background and anomalies (positive and negative ones) can be determined if statistical treatment of samples is possible. Then future water well results can be anticipated on the basis of a statistical approach. The simplicity of the procedure ensures easy and objective comparison of results, both in local and in regional hydrogeologic studies. This methodology, of course, cannot replace detailed and complex numerical models. It can, however, help to formulate general regularities and to prepare a way for definition of prevailing natural conditions, as described in the previous text, and to provide a first step on the way towards more detailed hydrogeologic data quantification.

To maintain one of principal advantages of the proposed methodologic approach and the transmissivity classification, i.e. quick and easy data analysis, simplifying assumptions were accepted, assumptions which usually do not affect results but which, however, should be taken into account. Some of them are as follows:

- Transmissivity (permeability) is considered to be a random function of a natural hydrogeologic environment. Therefore, the samples of data from wells are considered to be **random samples from an infinite population**. This is not the case of many available data samples, as many times **water wells are purposefully located into more promising sites**. As a consequence, the statistical distribution of a sample may be biased toward greater values, that is, the distribution is skewed more to the left when e.g. represented by a histogram.

More realistic statistical models can be obtained when data are pre-treated so that a selection of data from more permeable zones is made by choosing only selected values as representative, or by calculation of a weighted arithmetic mean.

- **Unsuccessful water wells** naturally should belong to a statistical sample. However, usually neither specific capacity nor yield are stated in archive reports. If the number of unsuccessful wells is known, an estimation of basic statistical characteristics is possible by graphical or numerical approximation of unknown values by using the presumed statistical, i.e. log-normal model distribution [Krásný (ed.) 1982]. In case of unknown number of failures, no remedy exists and as a result we have to consider the possibility that a sample where unsuccessful wells were probably omitted may over-estimate the actual transmissivity.

WP 5 Hydrogeological Decision Support System in Mountain Areas (HYDRODESUSMA)

5.1. Specification of a generic model for simulation:

Objectives and phenomena to be modelled :

During the project, we have been interested in developing a new methodology for evaluating catchment water balance taking into account climatic and anthropogenic scenarios. Many works have been developed in this area, especially with climatic scenarios but most of them are too complex, with many parameters that cannot be easily evaluated for reasons of cost, time or difficulties explained by the geomorphologic features of the area under study. Furthermore, in many works, the catchment is modelled as a unit or as a grid the cells of which are uniform and of small granularity level, which is time consuming for water balance evaluation and not appropriate for long-term analyses. Our goal is therefore to avoid these drawbacks and to develop a decision-support tool for long-term analysis of catchment water balance. For these reasons, we have designed, developed and tested a new approach to model and simulate catchments from a hydrologic point of view.

Our approach of modelling is based on the discrete and event-oriented theories and requires few parameters. Its originality is to be hierarchical and incremental: the model is based on concepts of slopes and parcels decomposition (see Figure 1) and for each parcel, basic phenomena are highlighted. Basic phenomena are (see Figures 2 and 5): evapo-transpiration, snow melting, surface and sub-surface run-off, infiltration, aquifer recharge and outflow, and river recharge. Relationships between these phenomena occurring on a parcel can be easily extrapolated over the catchment knowing the gradient relations between parcels and aquifer groundwater bodies.

The model is qualified as being generic because these phenomena can be modelled through empirical or theoretical formulae without modifying the structure of the catchment model.

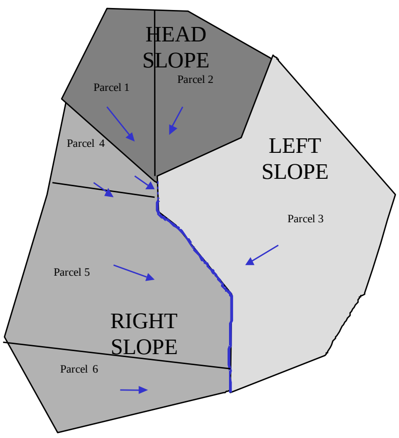

Figure 1 – Example of decomposition of a catchment into slopes and parcels

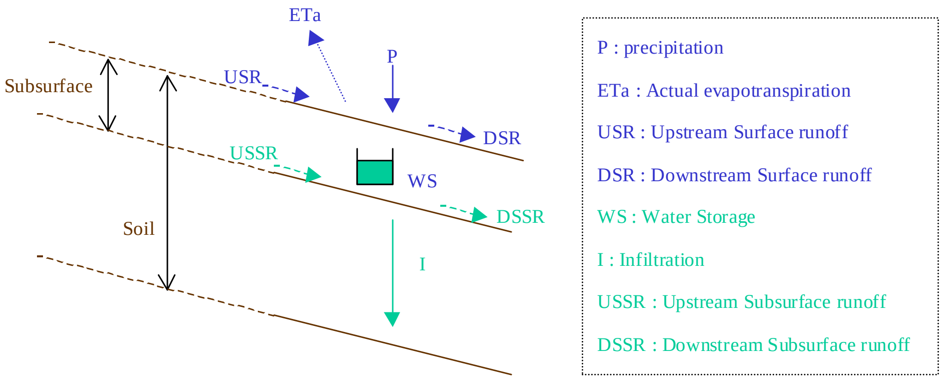

Figure 2 – Basic phenomena occurring of a parcel surface and sub-surface

Infiltration water recharges the groundwater body and consequently increases piezometric levels of the groundwater. The natural gradient of the groundwater leads to an outflow implying the decreasing of piezometric levels and the leading of the river outflow. In our study, we have considered that the catchment rock is homogeneous, non fissured and impervious. Consequently, there is no water loss in the rock substratum. As for water balance on the surface, we have to consider that there is may be an upstream flow coming from a dominant groundwater body. If we consider as previously that the surface is decomposed into parcels with respect to the homogeneity of slope and landcover, each parcel infiltration contributes to the groundwater recharge and the groundwater body can be viewed as a uniform hydrogeologic item. (cf. figure 3).

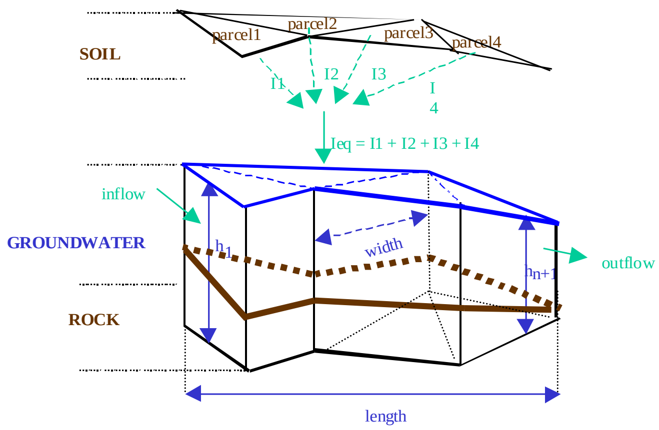

Figure 3 – Detailed phenomena involved in water balance of saturated zone

5.2. Approach of modelling

Every aforementioned fundamental phenomenon is represented by a behavioural model according to the sequential automata formalism. A sequential automata is a general formalism to describe the behaviour of any technical or physical system according to its interface (input/output) and its internal state. Figure 4 gives an example of modelling of snow melting using this formalism.

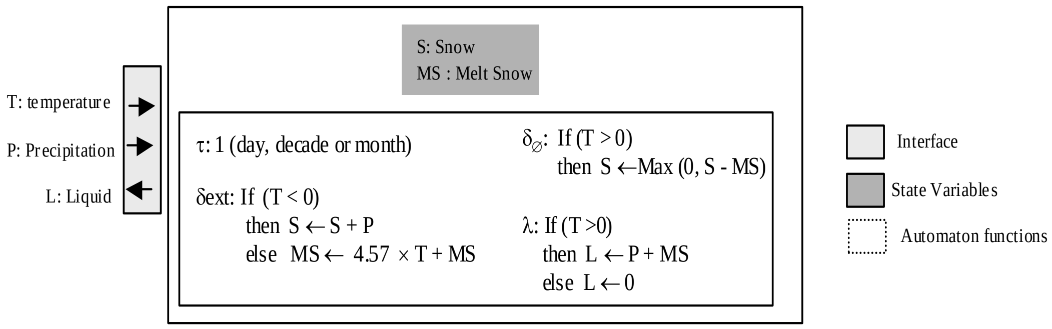

Figure 4 – Modelling snow melting with a sequential automata approach

The interaction of phenomena is represented by a structural model: it is a graph the nodes of which are sequential automata. Furthermore, the construction of the model is based on a hierarchical approach in order to support the modeller. For this reason, the graph is hierarchical: some nodes are structural models that are, at their turn, decomposed into models. Such modelling is interesting for two reasons. A behavioural model can be exchanged by another one without modifying the complete build up of the graph. That implies it is possible to implement and compare different formula for a phenomenon which is not precisely known. The second advantage is for the simulation. As the graph formalism is uniform (all behavioural models are sequential automata), the engine of simulation is independent from the phenomenon to be simulated. It is therefore possible to change components, to create new behavioural components without modifying the simulation engine. Figure 5 illustrates hierarchical and structural modelling of a parcel and point out how a behavioural model can be exchange by another one (Penman evapotranspiration model is replaced by Turc model).

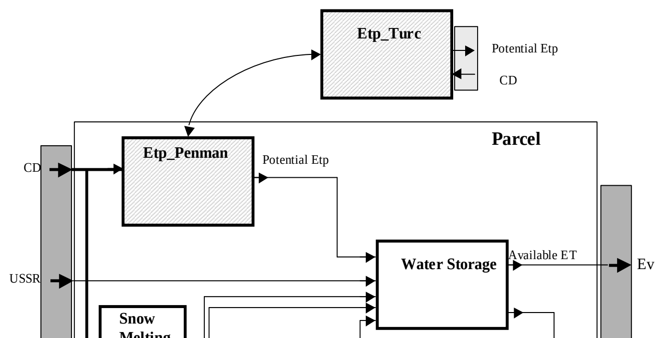

Figure 5 – Modelling snow melting with a sequential automata approach

5.3. Implementation of the model:

A software tool, HydroSimul, has been developed in Visual C++ to build up catchment models. The implementation of the model is based on an object-oriented approach. It means that every concept detailed in previous parts is defined as a class and is classified according to a taxonomy (see Figure 6). All sequential automata are derived from the class `BEHAVIOUR` and inherit from common properties: they have an interface (input/output), a list of state variables and the four fundamental functions. It means that these models have no private methods to be activated: all methods are derived from the `BEHAVIOUR` class. Structural models are derived from the class `STRUCTURE` and inherit from common properties: they have an interface (inputs/outputs), a list of internal links and a list of input/output external links. However, rules to interconnect their components are specific to their class and cannot be inherited but allow interconnections to be automatically established.

Creating the model of a catchment consists in instantiating models belonging to the taxonomy taking into account few parameters: number of hillslopes and their parcels, landcover and area of parcels, dominance between parcels, dispatching efficient rain coefficient, size of groundwater bodies and their piezometric levels, permeability of the wheathered zone. The model is then automatically build up.

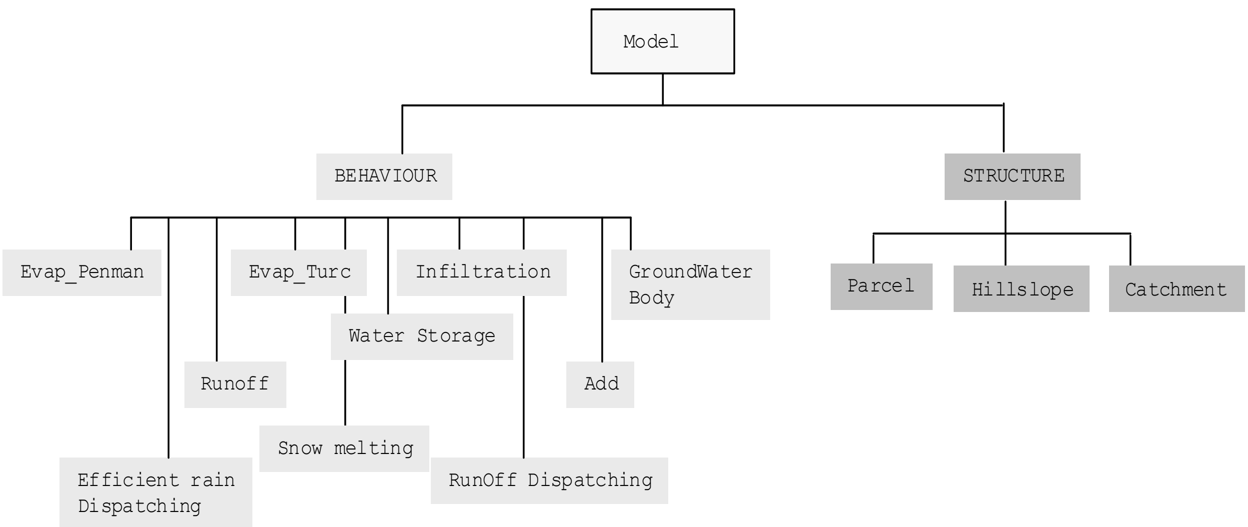

Figure 6 – Taxonomy of modelling classes

5.4. GIS application:

The LOWRGREP GIS was made during the project period, this part describes this evolution. In the first time, it was necessary to harmonize the GIS application in order for each partner to have the same data. After that, all the functions of the GIS in the LOWRGREP project will be presented. More precisely: GIS analysis (pollution load map and risk analysis) and the interaction of the GIS and the simulation tool.

a) GIS Harmonization:

During the building of the pollution load map, a problem appeared: all the maps are based on different data pools (information, scales, structure). Furthermore, the maps which should be implemented in the LOWRGREP-GIS data bank system, are constructed with different layers and description codes. So all partners took the decision to do a GIS workshop, where a framework for a standardized data bank system should be developed. A cooperation between LMU-Munich (Ch.Vornehm) and EMA (P-A.Ayral) has been established in this aim from October to December 2001, in Alès.

As a result, a proposal was worked out for the structure of the LOWRGREP-GIS. It consists in a common frame for the main information but with enough flexibility for optional data, giving information of characteristics and specifics problems for each single region. The content of tables that are associated to each information layer (general data and optional information of specific interest) was unified using a common frame of columns, whereas their content is specified by a standardised "key"-system.

The 14 layers which necessaries for each GIS partners are showed in the following figure:

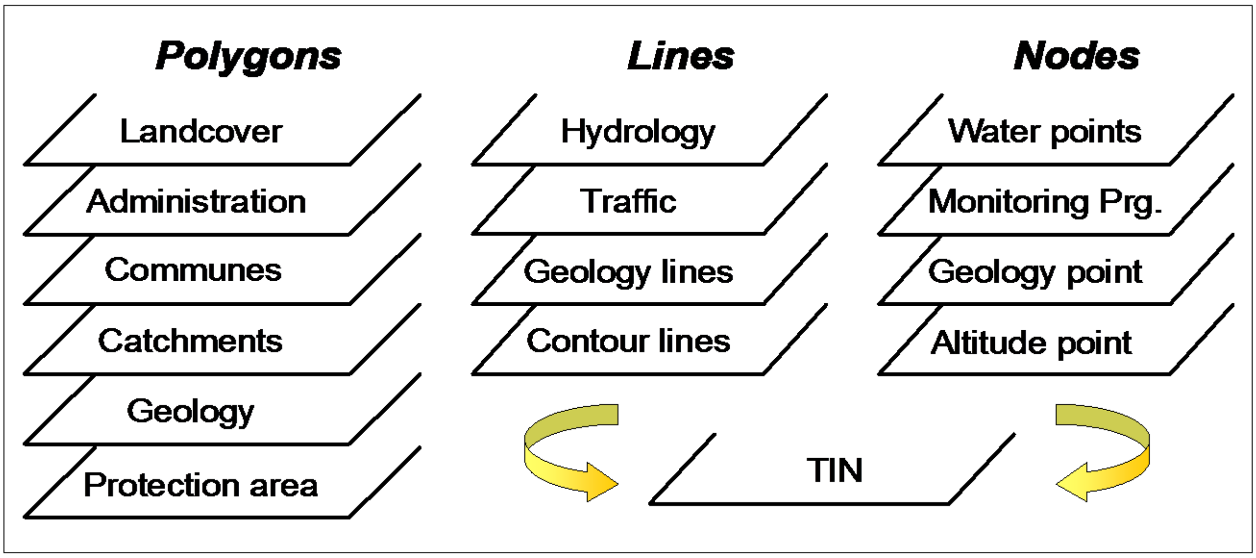

Figure 7: *Common layers for the LOWRGREP- GIS*

An example of harmonization is showed in the following table. It concerns the hydrology layers.

HYDROLOGY	**Lines**	
Name of column	**Contents**	
SHAPE	Polyline	
ID	Number of line	
KEY	One number for every type of surface water	
TYPE	Name of type of surface water	
NAME	If information exists	
INFO	Supplementary information (e.g. name of lake, name of village, …)	
CATCHMENT	Way of waters, different rivers; if information necessary	
LENGTH	Calculated by ArcView 3.2 (for segments or whole length of river)	
REMARKS	… if you have any	
HYDROLOGY	**300-349**	
KEY	**TYPE**	**Remarks**
300	**River**	
301	**Brook**	Natural
302	**Lake**	
303	**Pound**	
304	**Drain**	Artificial
305	Construction element	German partner (dam, barrage, weir…)
306	Pipe	Spain partner, Zaragoza
307	...	
308	...	

Table 1: *An example of layer harmonization*

The key in ***"blod"*** is common for each partner

The results of this harmonization have been presented in the working Draft : Standardization of a GIS an European Project. This report is in the Knowledge Base (Ref. 2003-00053). This document is also presented in the Deliverable 13.

b) GIS Analysis (pollution map and risk analysis):

The harmonization allowed making different analysis during the LOWRGREP project time. This analysis is presented in different work-package. First, this is the pollution load map which has been made. The GIS Layers are archived in the Deliverable 5: Maps of the vulnerability and pollution load (WP3 - D5). In a second time, the LOWRGREP-GIS has been used for illustrating the groundwater risk analysis. The maps are shown Deliverable 6: "Risk analysis of the factors influencing the groundwater quality in the mountain region" (WP4 – D6) and in the Deliverable 9: "Risk analysis of the factors influencing the groundwater resources in the mountain regions" (WP4 – D9).
At the end of the LOWRGREP project, the groundwater vulnerability has been validated and all layers which allow this analysis are archived in the Deliverable 13: "vulnerability evaluation module".

c) Vulnerability evaluation module:
The first idea for the vulnerability evaluation module was a GIS tool for vulnerability analysis of groundwater resources. A single tool could not be produced during the LOWRGREP project. Indeed, each partners have modified the vulnerability methodology that have been proposed by the Czech partners. The Deliverable 13: "vulnerability evaluation module" is the compilation of GIS analysis of all the partners, and the principal results are shown in the Deliverable 6: "Risk analysis of the factors influencing the groundwater quality in the mountain region" and in the Deliverable 9: "Risk analysis of the factors influencing the groundwater resources in the mountain regions".
The vulnerability map to acidification was first made with a methodology proposed by Charles University, Czech Republic. All the partners applied this method on the studied areas. This vulnerability method uses a Geographic Information System. The factors are presented in the following table:

Factor	Classification	Risk level	GIS data source
Altitude (A)	> 800 m	Risk 3	Contour lines and TIN (ArcView 3.2)
	550 m at 800 m	Risk 2	
	< 550	Risk 1	
Geology (G)	Granite	Risk 3	Geology Service
	Others	Risk 1	
Geomorphology (Gp)	Leeward slope	Risk 1	Contour lines and TIN (ArcView 3.2)
	Flat apical part	Risk 2	
	Windward slope	Risk 3	
Vegetative cover (Vc)	Grassland	Risk 0	CORINE Land Cover
	Scattered forest	Risk 0.5	
	Young forest	Risk 1	
	Mature forest	Risk 3	

Table 2: *Methodology of groundwater resource vulnerability to acidification*

The input data are: climatic data (winds, etc…); the description of the studied area (altitude, slopes) as well as the land use. In order to have a uniform methodology, the Corinne Land Cover database has been used. Geology of the region was also integrated in this vulnerability evaluation module.

Results show that this method which is very accurate in Czech Republic or in Germany needs to be improved in order to be applied in France or in Spain. For the French study area, the difference is mainly due to the fact that major atmospheric pollution comes in the Cévennes from another direction than in Czech Republic and the altitude factor are not a good factor for describing the rainfall areas. Moreover, with this methodology, the vulnerability degrees are overestimated. Another explanation is the fact that, in France, there is a very low risk level, and this is due to the fact that this area has very few industries and the National Park plays a role of control on this area.

So, it was necessary to adapt this methodology for the French study area. This work was made with collaboration of CNRS partner and with the National Park data (end users, members of steering committee). This operation is summarized in the following table:

Factor	Classification	Risk level	GIS data source
Precipitations (mm)	> 1750 mm	Risk 4	Contour lines and TIN (ArcView 3.2)
	1750 mm – 1500 mm	Risk 3	
	1500 mm – 1250 mm	Risk 2	
	< 1250 mm	Risk 1	
Geology (G)	Granite	Risk 3	Geology Service
	Others	Risk 1	
Geomorphology (Gp)	Slopes: N, NE, E, W, NW	Risk 0	Contour lines and TIN (ArcView 3.2)
	Flat zone	Risk 1	
	Slopes: SE, S	Risk 2	
	Slope: SO	Risk 3	
Vegetative cover (Vc)	Coniferous forest	Risk 4	CORINE Land Cover
	Mixed forest	Risk 3	
	Broad leaved forest	Risk 2	
	Mutation vegetation	Risk 1	
	Lower vegetation	Risk 0	

Table 3: *Adapting the methodology of groundwater resource vulnerability to acidification for the French study area*

The new methodology and the main results are presented in the Deliverable 6: "Risk analysis of the factors influencing the groundwater quality in the mountain region" and in the Deliverable 9: "Risk analysis of the factors influencing the groundwater resources in the mountain regions".

d) GIS for water balance evaluation:

In order to perform the water balance of a catchment, it is necessary to apply the methodology we have developed to set up the model on which the simulation is performed. This methodology consists in decomposing the catchment into two or several hillslopes; each slope is decomposed into parcels with respect to uniform land coverage and slopes; a groundwater body is associated with every slope and their outflow feeds the river.

The decomposition of the catchment into hillslopes has to be performed under the GIS by using a background map (.tif or .jpg) with contour lines, the river line and the limit of the catchment using a GPS or an expertise. The river and the catchment are the two main themes from which the decomposition starts. The catchment is then decomposed into hillslopes (see Figure 8) in such a way that every hillslope is supposed to feed the river with surface and sub-surface run-offs and has a groundwater body fed by the infiltration of its corresponding hillslopes.

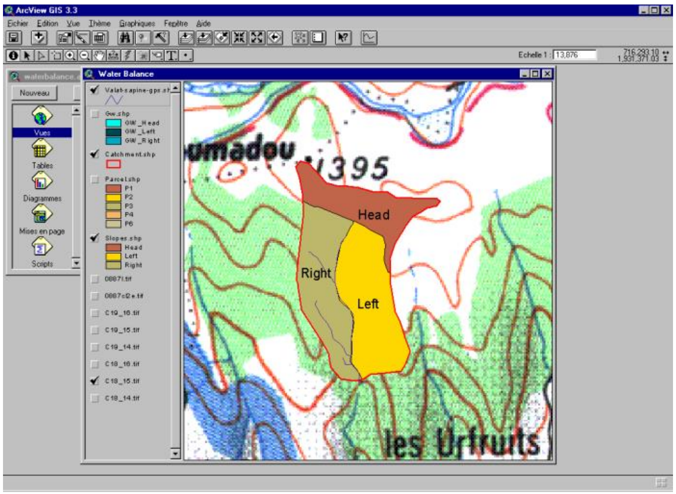

Figure 8 – Example of catchment decomposition into hillslopes

Hillslopes are therefore decomposed by the user into parcels in such a way that their land cover and gradients are uniform (see figure 9)

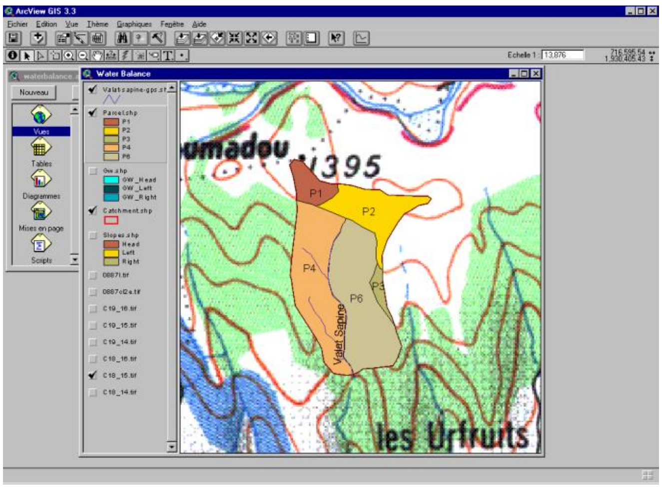

Figure 9 – Example of parcels identification

It is necessary to define groundwater bodies. In this release, a groundwater body is associated with each, so there will be three bodies the name of which is fixed by the user. It can appear redundant, but for future releases the software will be open to model several bodies. Parameters associated with every groundwater body are set up through a user-interface.
The GIS is used as an interface to build up the model and to activate the simulation. The simulation tool has been independently developed and is presented in a part above.

WP 6 Final results:

6.1. Testing of Hydrodesusma :

Data, expertise and software developed during the project have been stored in a Web Knowledge base whose access is explained in part « Dissemination of results » and detailed in a user guide located in Annex. In the following, we list the main work achieved during the project and give the reference of documents accessible through the Web-site: http://lowrgrep.site-eerie.ema.fr/.
Software tools developed during the project are: CUTTOS and HYDRODESUMA.
CUTTOS deals with the decomposition of baseflow recession curves in basins formed in hardrock regions. Its summary can be read under references:

- 2002-00134 : Pluricellular Model.-Cuttos
- 2002-00099 : Cuttos 2

HYDRODESUMA deals with the evaluation of water balance of catchments modeled using a methodology developed during the project. The evaluation is performed according to climatic and anthropogenic scenarios. The summary and complete release of documents relative to this work can be read under references:

- 2003-00045 : D15 - HYDRODESUSMA Final Release
- 2001-00005 : D11 - Specification of a generic model for simulation
- 2003-00036 : D14 - Release 3.3: modelling/simulation tool

The simulation tool is accessible under references:

- 2003-00046 : HYDRODESUSMA.exe
- 2003-00042 : HYDRODESUSMA : Installation & UserGuide

Work dealing the vulnerability evaluation can be read under references:

- 2003-00056: D5 - Maps of the Vulnerability and pollution load
- 2003-00057: D3 - Vulnerability evaluation module

Work dealing with water quality can be read under references:

- 2003-00031: D9 - Analysis of the factors influencing groundwater resources
- 2003-00038: GIS as a planning tool for groundwater quality assessment

Work dealing with chemical aspects can be read under references:

- 2003-00037: Geochemical zoning of soil and groundwater due to atmospheric deposition
- 2003-00001: D3 - Detailed analysis of the hydrochemical changes in Hardrock regions
- 2003-00039: Impact of ore deposits and anthropogenic activities an local hydrochemistry at "Silberberg", S-Germany

Work dealing with ground water runoff can be read under references:

- 2003-00015: D8 - an estimate of regional variation in ground water runoff from hard rock using the GIS

6.2 Dissemination of results:

All results (reports, data, software, expertise, publication) produced during the project have been collected in a Web Knowledge Base. A web application, called ECEMEWAM[1], has been therefore developed for two purposes:

- exchange of data (working documents, meeting announcement and minutes) between partners, all along the project. In this case, the Web site is accessible with a private access controlled by a path word.
- communication of the study and obtained results to the community of researchers and water management organism. In this case, the Web site is accessible with a guest access allowing only public documents to be read (like Deliverables).

ECEMEWAM address is: http://lowrgrep.site-eerie.ema.fr/. The detailed user guide of the Web Site is set in Annex

The main options for guest access are (see Figure 9):

- Presentation of the project:
- Description of goals
- Description of area under study

[1] European Centre for Mutual exchange of Experience in Wtaer Management in Moutain Regions

- Presentation of the partners
    - Institutions
    - Persons
- Official Documents (Deliverables)
- Access to the Knowledge Base as a guest including the acceptation of a chart

The list of all communications in conferences and publications in technical journals is given in Annex.

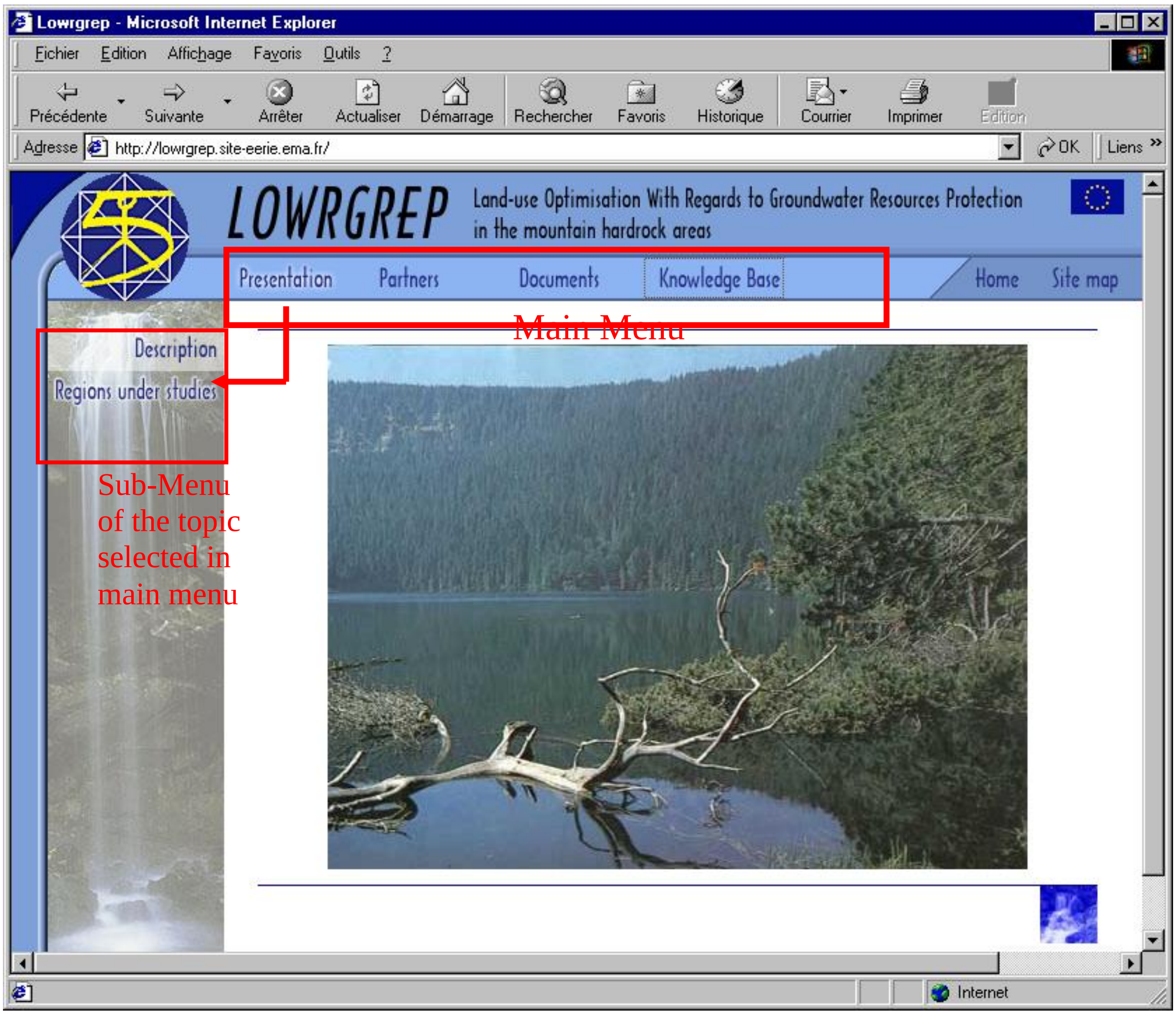

Figure 10 – Main Page of ECEMEWAM

243 documents have been stored in ECEMEWAM. They are of types: photos, textual documents, maps and software. Table 1 summarises how many documents have been stored

per category and per right access (partner or guest) at the date of the report delivery (March 13th 2003).

Category	Private access (Partner)	Guest access (Public)
Deliverable	31	All of them
Working drafts	22	0
Map	12	10 of them
Slides	10	4 of them
Administration	5	0
Meeting Announcement	4	0
Minutes	4	0
Publication	3	0
Communication support	101	48 of them
Unspecified	19	0
TOTAL	**221**	

Table 4 – *Number of ECEMEWAM documents per category and per right access*

6.3 Assessment of results and conclusions:

a) Atmospheric deposits and acidification risk:

The LOWRGREP project has been carried out using data related to various scales. One among the regional objectives of the project was to assess the effect of atmospheric deposition on the quality of groundwaters in mountain areas of Europe. The actual output of three-year monitoring is summarized in the following conclusions and recommendations. As expected, some differences have been found in the intensity of impacts of atmospheric deposition on water regime between Central Europe, represented by the Czech Republic and Germany, and Southern Europe, which included localities in France and Spain. The southern Europe, due to higher resistance of local rocks (higher proportion of limestones), lower absolute values of atmospheric deposition and more favourable climatic conditions (direction of prevailing winds), appears to be much better protected against impacts of acidification. On the other hand, some localities in Spain and France in particular showed certain signs, which characterized the onset of ecological disasters in Central and Northern Europe. Consequently, the issue of acid atmospheric deposition is to be considered an all-European problem that includes particularly the mountain regions, which suffer most from acid deposition with different intensity depending as said previously on geographical location.

The European Union has been very active during the last decade in reduction of total emissions. Large investments directed in implementation of the so-called desulphurization projects turned out to have been very successful. As demonstrated on the results achieved during the execution of the LOWRGREP project, the lower concentrations of sulphur in acid atmospheric deposition show prolonged trends. This general tendency is documented in Fig.1 showing the situation in Krušné hory Mts. Similar trend was observed on both sides of Šumava, i.e., in experimental catchments in the Czech Republic and Germany.

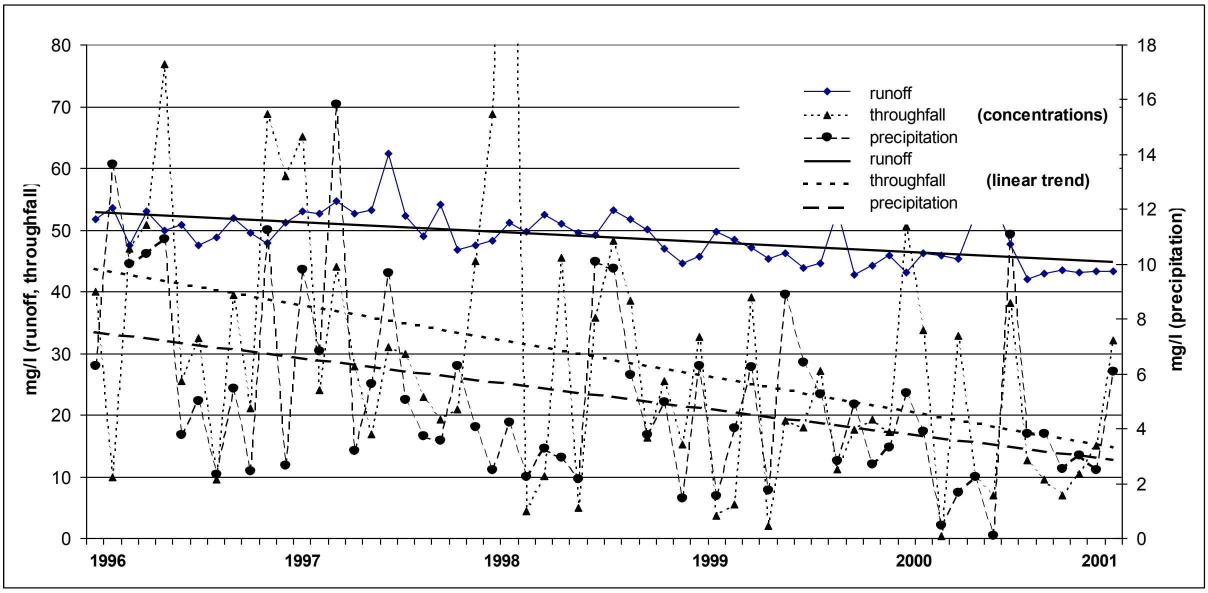

Figure 11: *Trend in SO_4 concentration in Krusné Mts, 1996 – 2001 (Hrkal, Z., Buchtele, J., Tikkanen, E., Käpyaho, A., Santrucek, J. 2002.)*

These optimistic conclusions, however, are corrected or even eliminated by new data. Whilst sulphur not long ago played the major role in acid atmospheric deposition, its role is nowadays taken over by nitrogen. All tested localities showed increased concentrations of nitrogen in atmospheric deposition, i.e., in the form of ammonia as well as in form of nitrates. This increase is obviously due to progressing intensity of motor traffic. This trend is even more dangerous than the earlier situation in sulphur pollution.

The same trends concerning sulphur and nitrogen has been observed in Germany: Evaluation of long term data from German steering group partner BITÖK made at the most northern site “Lehstenbach-catchment” (Bavaria) shows a displacement trend from SO_2 to NO_x as main atmospheric contaminant.

This kind of pollution and its rising tendency are even more dangerous than acidification caused by sulphur. The major source of acidification in Europe in the seventies till nineties of the last century was industrial complexes and power plants burning low quality coal. These sources were concentrated in several industrial districts such as the so-called „Black triangle“ (border zone between Poland, Germany and Czech Republic) and the Ruhr region in Germany. These sources of pollution are nowadays much less important on all-European scale, but on the other hand the impact of acidification on the quality of surface and groundwaters remains more or less the same due to the change in composition of atmospheric deposition in which formerly prevailing sulphur was substituted by nitrogen. The Southern Europe has earlier been safe as far as the acid atmospheric deposition is concerned since the sources of pollution were located in Central Europe and the prevailing atmospheric circulation transported pollutants to the north.

The LOWRGREP project tried to express in the form of maps of vulnerability the exposure of single types of natural environment to acid atmospheric precipitation. The information capacity and ability of these maps were tested on samples of groundwater and their quality under dynamic conditions. The results brought a number of practical conclusions to be considered. It is to be noted that the majority of factors affecting the intensity and impacts of acid atmospheric deposition on quality of groundwater are of natural character and cannot be influenced by human activities. These parameters include lithology, type of soil, altitude above sea level, morphology or exposure of slopes to prevailing direction of winds. On the other hand, there exists a factor, which can be considerably influenced by human activities. This factor includes the character of vegetation cover, the forests in particular. The studies came, at first sight, to a paradoxical conclusion that the existing matured forest has a negative impact on the quality of surface and groundwater because the forest obviously increases the intensity and impacts of acid atmospheric deposition. The explanation appears to be logical having been verified at numerous localities.

The acidification risk for single regions was depicted by vulnerability maps. From the German experience we can precise that: “There calculation follows the guidelines of HRKAL, from Charles University, Prague, who developed this method for Czech regions. It is to be noted that the method was developed for test sites with a high morphological relief. Because of the smaller scale investigations, differences of the relief at German sites vary between the studied areas. As a result, different methods were necessary to monitor and to describe acidification processes: 1) For regions with a lot of information physico-chemical data such as region Rötz-Schönthal, monitoring of the development of acidification processes can be made for single locations to get an good overview of the whole situation. Because of the low morphological heights (below 700 m a.s.l, morphological variation: about 200 m), method of HRKAL has to be done without main parameter morphology. 2) At sites such as region

Bodenmais-Regen with a relief from 500 m a.s.l to the top of mountain (1457 m a.s.l) HRKAL-method is a good option to get an overview of the situation in a larger scale. Compared to results for larger test sites, there exists a lower limit for the size of a catchment to get meaningful results. Minimum size of the catchment must have several tens of square kilometers, below these limit results the interaction of large scale effects on small scale monitoring is not useful. Besides the higher relief it is an advantage to have different types of land use. Areas with monotonous features (morphology, land use) show mostly unsatisfying results such as for Lehstenbach-catchment. As a conclusion it can be said, that this kind of simulation/evaluation focusing on atmospheric input in large scale must be adapted carefully into the smaller scale, because data base and local problems do not really deal with large scale effects. For investigations on the impact of large scaled effects at small sites it is necessary to enhance the monitoring area to avoid scaling effects at the border region of the monitored site (cause of the different dimensions it can happen, that in the whole area all data trend in the wrong direction). So beside local information regional data are of interest, too.
Hrkal's method has been applied on the French site (Mont Lozère, Southern part of Massif Central). It appears that the method had to be adapted to the region, by giving different weights to parameters like wind direction, altitude and vegetative cover.
The forest, coniferous in particular, in areas affected by acidification catches and absorbs larger volumes of dry atmospheric deposition. Deforestation or forest extinction always resulted in decrease of acidification. However, to propose simple removal of forest cover in areas affected by atmospheric deposition would be an absurd simplification of the given problem and its separation from a broader context. Fast lumbering or deforestation, particularly in mountain regions having rough morphology, would cause intense soil erosion thus giving rise to other problems. On the other hand, gradual forest rejuvenation and change of its generic composition appears to be the best method how to improve its power and resistance to impacts of acidification. In contrast, planting of any monoculture (spruce in particular) appears to be very dangerous. As follows from experience gathered in the Krušné hory Mts, a mixed forest with higher proportion of deciduous trees is the best tool to reduce the impact of acidification. However, it is to be kept in mind that any intervention in vegetation cover represents only a subsidiary improvement because the primary task is to reduce or eliminate the sources of acid atmospheric deposition.

b) Conclusions concerning acidification and atmospheric deposits:

- The issue of acidification of surface and groundwaters in mountain regions of Europe remains still relevant and contemporary problem to be resolved,
- The dominant role of sulphur in acid atmospheric deposition has been gradually taken over by nitrogen, mostly on regional scale. The attenuation of heavy industry and desulfurization of power plants brings positive results. However, more intense motor traffic is responsible for increase of nitrogen emissions,

- In regions affected by acid atmospheric deposition, the existence of full-grown, particularly coniferous forest, aggravates the quality of surface and groundwaters. This situation is caused by more intense impact of dry deposition, which prevails in atmospheric deposition.
- Mixed forest with higher proportion of deciduous species appears to be the most effective tool to reduce the impacts of acidification.

c) The issue of agricultural activities :

The majority of mountain regions of Europe are cultivated to various extent. Whilst the plant-growing is rather marginal, much important is the animal farming and its role in acidification. One of the subsidiary objectives of the LOWRGREP project has been the assessment of impacts of animal farming on the quality of surface and groundwaters. Selected experimental catchments were monitored in the Krušné hory and Šumava Mts as well as in both Spanish mountain regions where the cycle of nitrogen and intensity of denitrification processes were studied. The major conclusion derived from these studies was a common statement that extensive animal farming does not have any negative impact on the quality of local surface and groundwaters. The term extensive animal farming is in the LOWRGREP project defined as animal husbandry on pastures and grasslands during vegetation period, thus from early spring till late autumn at a cattle density not exceeding 1 cattle unit per 0.5 ha. Under such conditions, all forms of nitrogen are close to natural background values.

This method of exploitation of mountain regions does not only do any harm to the hydrosphere but can be recommended as an ideal tool for reasonable exploitation of grasslands.

d) The impact of land-use on groundwater and drainage conditions:

As concerns the quantitative assessment, the major emphasis was put on determination of groundwater resources in mountain regions and appraisal of factors, which may affect the drainage conditions. The model solutions showed that all mountain regions, due to favourable climatic conditions and rough morphology, have large groundwater resources. The rate of groundwater flow varied mostly around 10 L/s/km^2, and locally even exceeded this value. Two softwares (CUTTOS and Hydrosimul) were developed and employed within the LOWRGREP project enabling to assess individual elements and the role they play in water balance. Their use as well as the application of other models such as Brook or SACRAMENTO and CHAC (Hydrometeorological Assessment of inputs and flooding developed in Spain) allowed to test the impact of various methods of land-use on drainage both in absolute values and proportion of single elements in hydrological balance. The studies proved negative impact of sheet runoff and extensive consolidation of land, which resulted in acceleration of total sheet runoff and reduction of retention capacity of the given area. Similar negative impact on drainage showed forest damaged by bark-beetle and affected by acid atmospheric deposition. Only the decline in forest condition itself resulted in rise of water discharge during floods as has been documented in model studies.

e) Conclusions on land-use and drainage condition:

- Deterioration of forest condition is reflected in climax water discharges, their acceleration and reduction of retention capacity of the landscape,
- Similar impact shows consolidation of land and sheet runoff.
- Besides of morphology the covering layers plays an important role for drainage conditions and the groundwater reservoir
- The conditions of top soil and weathering zone are controlled by the situation of the forest, the main protection against erosion processes.

And more generally a **sustainable administration of the water resources** bound to the aquifers of the hard rocks should outline:

- The use of these aquifers, preferably, and in some cases exclusively, for populations' supply.
- The valuation of the relationship of these aquifers with the maintenance of the rivers flow and with it, the conservation of their fauna and flora.
- Establishment of rules of exploitation for the Authority Water that prohibits or limit the use of this waters in agriculture of irrigable with cultivations of strong demand of water (corn, medic…).

The European Directive of Water establishes the necessity of delimitation of all the water bodies that they supply to populations, this delimitation and the rules of protection of those bodies it can be the best future method in sustainable administration of this resource.

f) Use of Geographic Information System (GIS):

GIS have been applied by the different partners. Series of data are linked with vulnerability to acidification.

GIS can be linked with Hydrosimul, the water balance evaluation software. This tool allows water balance to be set up for any catchment modelled following a pre-defined methodology. The evaluation consists is computing by simulation the river outflow and the groundwater body variation according to climatic scenario or/and anthropogenic scenario over one or several years. This tool constitutes a decision support to point out how a catchment balance can evolve according to land-use modification.

Conclusion: GIS can be linked with hydrosimul Geographical Information Systems reveals to be necessary and powerful way to collect data on a uniform and easy to understand support. It is not only a support to collect data but also a support for reasoning, exchanging expertise, and pointing out results. It constitutes a perfect support because it allows expert to communicate between them from different points of view but also results to be demonstrated to non experts of information system such as decision maker or person in charge of water management. During the project, we demonstrate how to use a uniform methodology to define a common GIS and to show up how to integrate the specific tool Hydrodesusma, a water balance simulator, into the GIS.

g) Modelling and simulation tool:

A modelling and simulation tool, named Hydrosimul, has been built up for the calculation of water balance on a catchment area. This simulation tool is coupled with a GIS. The tool is designed in such a way that it enables the user to simulate the land use, through variations of runoff coefficient with the time (for instance for the next thirty years). So it is possible to predict, at least in a rough way, the influence onto run-off of changes in land-use of parcels or regions. It is also possible to simulate variation in the climate (part of the input data are climatic data) for the same lag of time. So, this software permits to evaluate the influence of possible global change onto the run-off and onto infiltration in a time lag of several decades. Combination of anthropogenic changes with land use and global change with climatic data is possible. Simulations have now to be realised onto catchments where measured data are available.

Conclusion: this prototype of software coupled with a GIS is the core of a new decision support system which takes into account the land-use and which calculates the infiltration on a long period of time

h) ECEMEWAM:

A web site has been built up with a Knowledge Base. This site is built up in such a way that all kind of documents (slides, reports, maps, etc…) can be stored into this Knowledge Base and extracted. Different levels of confidentiality permit to use the site as a tool for general information (public level with no confidentiality) as a tool for exchanging information between partners (with the level of confidentiality of “partners”). Special attention has been given to the user friendliness of the knowledge Base. User guide is available and has been given to every Partner.

Conclusions:

- The site can be used for a general information by every citizen.
- It can also be used as a link between partners and as a place where to find information for further exchanges on the topic of water and management of water (looking for detailed information, experts, other experiences…). This is the European for Mutual Exchange of Experience in Water Management in Mountain Regions (ECEMEWAM).

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References:

1) technical references:

APPELO, C.A.J., D. POSTMA (1993): “Geochemistry, Groundwater and Pollution”, Rotterdam (Balkema), 536 pages.

BATU, V. (1998): “Aquifer Hydraulics – A Comprehensive Guide to Hydrogeologic Data Analysis.” ,New York (John Wiley & Sons, Inc.) 0-471-18502-7, 727 pages.

BENTZ, A. & MARTINI, H.-J. (1969): “Lehrbuch der Angewandten Geologie”,- Band 2, 2. Teil (Abschn. 6: Hydrogeologie, pp 1357-1543); Stuttgart (Enke).

BUSCH, K.F., LUCKNER, L. (1993):“Geohydraulik“. 3. Ed., Lehrbuch der Hydrogeologie Band 3, 50 Tab., Stuttgart (Borntraeger), ISBN 3-443-01004-0, 497pages.

CHAPELLIER, D. (1992):“ Well Logging in Hydrogeology.“ Rotterdam (Balkema). ISBN 90-5410-207-1.

DAGAN, G. (1989): “Flow and Transport in porous formations”, 113 Abb.; Berlin (Springer), 465pages.

DE MARSILY, G. (1986): “Quantitative Hydrogeology”, San Diego, London, (Academic Press), 440 pages.

DOMENICO, P.A. & SCHWARZ, F.W. (1997): “Physical and Chemical Hydrogeology”, New York (Wiley & Sons) ISBN 0-471-59762-7, 506 pages.

DRISCOLL, F. G. (1989): Groundwater and Wells. 2. Ed., Johnson Filtration Systems Inc., St. Paul, Minnesota, USA, 1089 pages.

SINGH V. Ed.(1995) "Environmental Hydrology", Kluwer Academic Publ., Dordrecht, 479 pages.

2) legislative references :

Directive 80/68/EEC on the protection of groundwater against pollution caused by certain dangerous substances.

Directive 82/176/EEC and 84/156/EEC on limit values and quality objectives for mercury discharge.

Directive 83/513/EEC on limit values and quality objectives for cadmium discharges.

Directive 84/491/EEC on limit values and quality objectives for discharge of hexachloro-cyclohexane.

Directive 86/280/EEC on limit values and quality objectives for discharges of certain dangerous substances included in list I of the Annex to Directive 76/474/EEC

Directive 88/347/EEC amending Annex II to Directive 86/280/EEC

Directive 90/415 on dichloroethylene, trichloroethylene and trichlorobenzene.

Directive 91/414/EEC Pesticides

Directive 91/476/EEC concerning the protection of waters against pollution caused by nitrates from agricultural sources.

Directive 98/83/EC concerning quality of water intended for human consumption.

Directive 200/60/EC concerning water policy